

Tropical Cyclone Formation: Physical Processes and Predictions

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Award No.: N0001402WR20185

LONG-TERM GOALS

The long-term goal is to improve the prediction of the intensity and structure of tropical cyclones (TCs) at their formation stage so that hazardous effects to naval operations can be evaluated in advance and minimized.

OBJECTIVES

- (1) To improve our understanding of the physical processes associated with TC formation, especially the relative roles played by large-scale forcing and mesoscale systems.
- (2) To improve the skill of predicting TC formations in the 120-h forecast range, and their early-stage track and structure.

APPROACH

(1) Case studies in TC formation making use of both analysis data and numerical simulations. (2) Utilize the Systematic Approach framework in TC formation predictions by verifying operational global models. In light of the successful Systematic Approach to guiding track forecasts, a similar system is to be established for early detection of TC formations. To do this, a database of verification statistics and identified error mechanisms for several operational global models will be built. (3) Exploring the potential of a high-resolution regional model in improving TC formation predictions. This approach is expected to optimize detection rate, and minimize the false alarm rate. The most likely model-testing methodologies will be addition of observed surface wind data, and better initialization of mesoscale systems in the model initial fields through satellite data. (4) Examine environmental parameters associated with TC formations in long historical records. This approach is possible with the availability of a long period of reanalysis data and TC best tracks. Besides a basic understanding of the environmental conditions in which TCs form, another goal is to identify a useful formation potential parameter especially for the western North Pacific (WNP) that will be applicable in real-time forecast situation.

WORK COMPLETED

- (1) Numerical simulations have been performed on Typhoon Robyn (1993) in the western North Pacific using the PSU/NCAR MM5 model. This case was chosen because of availability of

Report Documentation Page			Form Approved OMB No. 0704-0188		
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1. REPORT DATE 30 SEP 2002		2. REPORT TYPE		3. DATES COVERED 00-00-2002 to 00-00-2002	
4. TITLE AND SUBTITLE Tropical Cyclone Formation: Physical Processes and Predictions				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Department of Meteorology,,Naval Postgraduate School,589 Dyer Road,,Monterey,,CA, 93943				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT The long-term goal is to improve the prediction of the intensity and structure of tropical cyclones (TCs) at their formation stage so that hazardous effects to naval operations can be evaluated in advance and minimized.					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT Same as Report (SAR)	18. NUMBER OF PAGES 6	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

observations from two intensive observational periods during the TC motion (TCM-93) field experiment, and one of the hypotheses of the experiment about contributions from mesoscale convective systems to the formation of Robyn. Some of the results have been presented in conferences (Cheung 2001, 2002a). A manuscript summarizing the results is under preparation.

(2) A study has been published (Cheung and Elsberry 2002) on verifying the Navy Operational Global Atmospheric Prediction System (NOGAPS) in forecasting TC formations in the WNP during 1997–1999. To realize the Systematic Approach to TC formation forecast guidance, we have been collecting various operational global model forecast fields starting from 2001. These operational models include the NCEP/AVN, NOGAPS, Germany’s Global Weather Prediction Model (GME), Japan Meteorological Agency’s Global Spectral Model (GSM), and Taiwan Central Weather Bureau’s Global Forecast System. A web page (<http://www.met.nps.navy.mil/kwcheung/>) has been set up for convenient visualization of the near real-time forecast data, especially those parameters that are closely related to TC formation. This also serves the purpose for us to get familiar with the different model characteristics.

(3) Navy’s Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS) was chosen to be the testing model for regional TC formation predictions in the WNP because of its convenience in running in the continuous data assimilation mode, and availability of NOGAPS data (as first guess fields) and observations in the Fleet Numerical Meteorology and Oceanography Center. The model has been set up using the computer resources provided by the Naval Oceanographic Office’s Major Shared Resource Center. Since COAMPS is currently under a transition to a new parallel version (COAMPS v.3), we are in the process of comparing it with the previous version and testing new hardware before beginning intensive runs. Some of our preliminary results were presented in Cheung (2002b).

(4) Although the basic large-scale environmental conditions for TC formations are well-known (e.g., McBride and Zehr 1981), detailed information on some of the dynamical parameters associated with TC formations is not well documented, especially for the WNP where there exist a number of different formation patterns (Ritchie and Holland 1999). Several parameters closely related to TC formations have been examined for cases in the period 1990–2001. These parameters include sea-surface temperature (SST), vertical wind shear, relative humidity, convective available potential energy (CAPE), and mid-to-upper-level moisture content. They were computed from NCEP reanalyses and GMS-5 satellite imagery.

RESULTS

Based on the MM5 simulations, it was found that many of the features associated with the formation of Typhoon Robyn could be realized in the model grid with 27-km resolution. These features include the initial near-surface convergence and subsequent frontal line, and then two consecutive convective events that led to the intensification to a tropical depression. However, great sensitivity of the simulations to the model physics was found. As in other tropical simulations (e.g., Davis and Bosart 2002), a faster intensification was obtained using the Bett-Miller cumulus parameterization than other schemes. Similar to other simulations of TC intensification (e.g., Braun and Tao 2000), our simulations are also sensitive to the choice of boundary layer parameterization. With certain parameterization, more than one TC is spun up in the model, which is a situation similar to the false alarms predicted in some global models. We will summarize and diagnose these sensitivities in a forthcoming manuscript. In addition, we will perform MM5 simulations with higher resolution to better resolve the cloud

systems associated with the convective events before Robyn's formation to gain further understanding of their contributions in the vorticity budget of the cyclone.

A set of criteria is developed in Cheung and Elsberry (2002) to identify TC formations in NOGAPS analyses and forecast fields. Then the NOGAPS forecasts of TC formations from 1997 to 1999 are verified relative to a formation time defined to be the first warning issued by the Joint Typhoon Warning Center. The successful NOGAPS predictions of formation within a maximum separation threshold of 4° latitude is about 70–80% for 24-h forecasts, and drops to about 20–30% for 120-h forecasts. The success rate is higher for formations in the South China Sea and between 160°E and 180°E, but is generally lower between 120°E and 160°E (with a low-level monsoon confluence region with marked cross-equatorial flow). Therefore, it is concluded that the skill of NOGAPS in predicting TC formations with a monsoon confluence region pattern is lower than for other formation patterns. However, the number of false alarms in NOGAPS is also quite high. Several large-scale features are compared for the successful and failed predictions during the three-year period. In general, the failed predictions have a slightly larger westerly vertical wind shear south of the TC formation location than in the successful predictions. The predicted relative humidity of the failed predictions is lower than in the successful formation forecasts. Thus, predicting too large a vertical wind shear and too dry an environment may be partially responsible for the failed cases.

It is well known that TC activity in the WNP has its peak during the three months from July to September. This is also the case for the 405 cases we examined in the period 1990–2001. The first reason is the seasonal warming in the Pacific so that a larger area has SSTs greater than that required for TC formation in the summer. The formation locations in these three months are usually in the higher latitudes due to the northward shift of the monsoon shear line (with low zonal vertical wind shear). From calculations of the CAPE, it was found that the values in the vicinity of TC formations have a near-normal distribution with an average of about 1200 J kg^{-1} . However, this is lower than the maximum value (above 1400 J kg^{-1}) in its climatology. With respect to the moisture content, the GMS-5 IR channel-3 brightness temperature was also examined for 196 cases during 1996–2001. It was found that most of the formation cases have an average (within an area centered on the formation) brightness temperature of around 220 K. We are in the process of comparing this with the associated moisture climatology. Some future work in this direction is to determine how these seasonal variations of the large-scale environmental parameters are further modulated by short-term (intraseasonal) and/or mesoscale parameters such that the observed frequency of TC formations is better explained.

IMPACT/APPLICATIONS

The observational and numerical simulation studies of historical TC formation cases in the WNP will strengthen our understanding of the variability of TC activity in the basin, as well as the formation mechanisms of individual storms.

The verifications of operational global models and identification of their error mechanisms will enable the establishment of a Systematic Approach to guiding early detection of TC formations.

The regional COAMPS forecast system for the WNP has the potential of outperforming the global models in maximizing the TC detection rate, and minimizing the false alarm rate.

SUMMARY

The physics of tropical cyclone formations is studied with both observational and numerical simulation approaches. The observational studies of historical cases identify essential environmental parameters during tropical cyclone formation, such as the moisture requirement and convective instability. Numerical simulations of these historical cases using a mesoscale model such as the PSU/NCAR MM5 enable us to look into interactions between large-scale flows and mesoscale cloud systems. Emphasis of our work is also on practical improvement of the skill of predicting formation of individual cyclones in the 120-h forecast range. This will be accomplished by a systematic approach to utilize current operational global model forecasts, as well as introducing a regional high-resolution COAMPS component.

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